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Starspot temperature along the HR diagram

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Abstract. The photospheric temperature of active stars is affected by the presence of cool starspots. The determination of the spot configuration and, in particular, spot temperatures and sizes, is important for understanding the role of the magnetic field in blocking the convective heating flux inside starspots. It has been demonstrated that a very sensitive diagnostic of surface temperature in late-type stars is the depth ratio of weak photospheric absorption lines (e.g. Gray & Johanson 1991, Catalano et al. 2002). We have shown that it is possible to reconstruct the distribution of the spots, along with their sizes and temperatures, from the application of a spot model to the light and temperature curves (Frasca et al. 2005). In this work, we present and briefly discuss results on spot sizes and temperatures for stars in various locations in the HR diagram.

Key words. Stars: activity - Stars: variability - Stars: starspot

1. Introduction

Within a large program aimed at studying the behaviour of photospheric surface inhomogeneities of late-type stars, we have observed some RS CVn binaries and young solar-type stars with activity levels intermediate between the Sun and the active RS CVn stars (Table 1). To get accurate spot sizes and temperatures, we have obtained and solved for contemporaneous rotational light and temperature curves applying the method described in our previous works (Biazzo et al. 2005, Frasca et al. 2005). The temperature curves are derived from photospheric line-depth ratios (LDRs).

Table 1. Star sample.

Star	Sp. Type	ΔT	$A_{\rm rel}$	$\log g$
IM Peg	K2III–II	453	0.106	2.28
HK Lac	K0III	762	0.131	2.45
λ And	G8III	877	0.076	2.50
VY Ari	K3-4V–IV	836	0.144	3.32
κ1 Cet	G5V	874	0.018	4.44
HD 206860	G0V	1012	0.033	4.44

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2. Observations

In order to derive LDRs, spectroscopic observations have been obtained at:

- Catania Astrophysical Observatory (Italy) with the 91-cm telescope (IM Peg, HK Lac, λ And, VY Ari, κ1 Cet, HD 206860);
- Observatoire de Haute-Provence (France) with the 193-cm telescope (HD 206860).

Photometric observations have been collected at:

- Catania Astrophysical Observatory with the 80-cm Automated Photometric Telescope (APT) and with the 91-cm telescope (VY Ari, IM Peg, HK Lac, HD 206860);
- Fairborn Observatory (Arizona, USA) with the T4 0.75 m Automatic Photoelectric Telescope (κ1 Cet);
- Ege University Observatory (İzmir, Turkey) with the 48-cm Cassegrain telescope (λ And).

3. Photometric and temperature curve model

As shown in Fig. 1, we find a good correlation between observed V and B magnitudes and temperature modulation from LDR analysis. So, in order to reproduce simultaneously the temperature and light curves, we have used the spot model described in Frasca et al. (2005). This model allows us to determine the geometric parameters of the starspots (angular radii, longitudes, latitudes) as a function of the relative spot temperature (T_{sp}/T_{ph}). We have shown that both light and temperature curves can be adequately fitted with very different values of spot temperatures T_{sp} and sizes A_{rel}. Therefore, we have obtained two grids of possible solutions for the light curve and the temperature curve, respectively. The intersection of these two solution grids provides the correct values of T_{sp} and A_{rel} for our star sample (Fig. 2). The simultaneous light and temperature final solutions for λ And are displayed in Fig. 1 with continuous lines together with a map of the spotted photosphere, as seen at two different phases. Results of solutions are reported in Table 1.

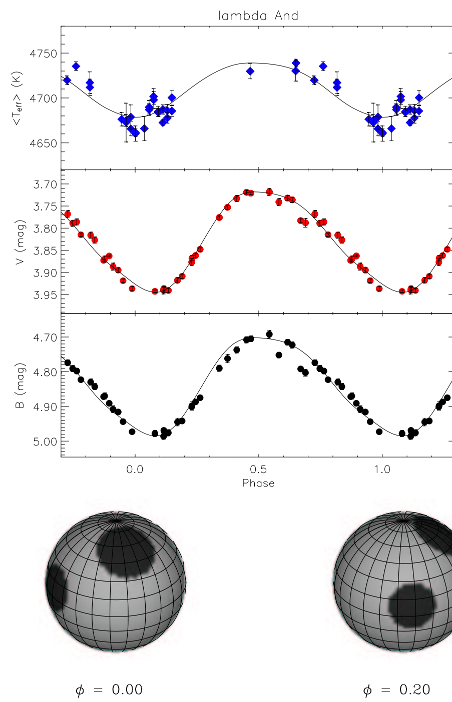

Fig. 1. *Top*: rotational modulation of the temperature, V and B magnitudes for λ And. The dots represent the observational data, while the continuous lines are the synthetic solutions obtained by means of our spot model. *Bottom*: schematic maps of the spotted photosphere.

In spite of the limited set of data, it appears that the temperature difference ΔT between the quiet and spotted photosphere is correlated with the stellar surface gravity, i.e., dwarf stars tend to have smaller and cooler (relative to their photosphere) spots compared to the giants. This behaviour could be related to the scaling law $B \propto P^{0.5}$ in which the magnetic field strength increases with the photospheric pressure, directly dependent on the gravity (Saar & Linsky 1986, Saar 1987). However, since the main sequence stars have a lower activity level than the RS CVn stars,

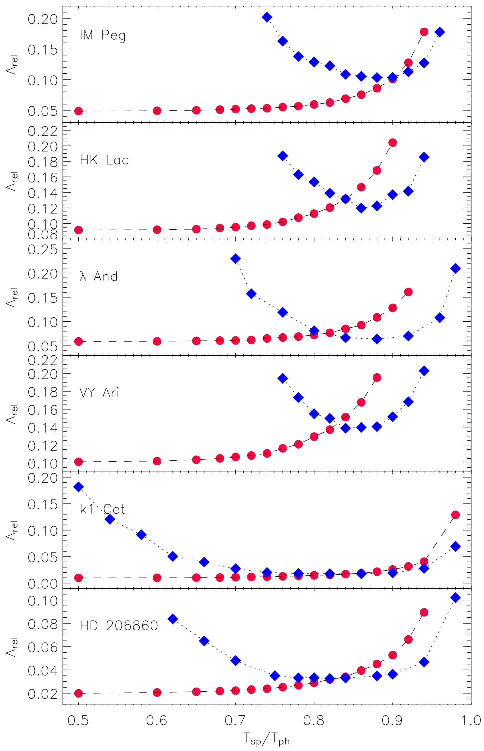

Fig. 2. Grids of solutions for temperature curves (diamonds) and light curves (dots) obtained adopting the atmospheric model developed by Kurucz (1993). Going from the top panel to the bottom panel, the solution grids from low-gravity stars ($\log g \approx 2.5$) to MS stars ($\log g \approx 4.5$) are displayed.

we cannot exclude a dependence of the starspot parameters on the activity level.

4. Conclusions

From the combined analysis of contemporaneous temperature variations and light curves, we have obtained unique solutions for the spot temperature and filling factor of some RS CVn and solar-type stars. The spot temperatures derived by us are closer to sunspot penumbrae than sunspot umbrae, probably due to the larger size of the penumbrae compared to the umbrae and the larger weight of the former in determining the spectral line-depths. A possible dependence of ΔT on stellar gravity is also indicated by our limited data set. We are still collecting data for both dwarf and giant stars with different activity levels in order to reach more definitive conclusions.

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